LBNL No. 54984

HPCBS

High Performance Commercial Building Systems

Evaluation of Persistence of Savings from SMUD Retrocommissioning Program

Final Report

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May, 2004

CIEE B-03-01, LBL#81BS

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Executive Summary

Commercial building retrocommissioning activity has increased in recent years. Retrocommissioning is a process of identifying and implementing system improvements in existing buildings, with an emphasis on using low cost operation & maintenance tune-ups and diagnostic testing instead of capital intensive retrofits.

This report discusses a recent study of retrocommissioning persistence, conducted by LBNL for the Sacramento Municipal utility District (SMUD). The objective of this study was to examine a selection of the 17 buildings (prior to 2003) that participated in SMUD's program and estimate the persistence of energy savings and measure implementation. The SMUD retrocommissioning program's two primary goals are to reduce overall building energy consumption and guide the customer toward more far-reaching improvements and energy efficiency awareness.

The complete report contains the following documents:

- Executive Summary & Final Report
- Appendix A: Data Analysis Methodology Details
- Appendix B: Site-by-Site Energy Analysis Results
- Appendix C: Interview Notes - Raw Data
- Appendix D: Data Analysis Spreadsheet

The Report is organized in five sections. The Introduction describes retrocommissioning background, persistence of savings issues and previous related work. The Methodology section provides an overview of the data analysis procedures. The Results and Discussion sections highlight and interpret key findings. The Summary section provides conclusions and recommendations.

Data Collection & Analysis

The project phases progressed as follows:

- A background review of persistence work,
- Development a of project plan and site selection,
- Data collection and analysis, and
- Development of recommendations and the final report.

The selected sites included six office buildings, one hospital and one laboratory. For report distribution and to protect the privacy of the study sites, the locations have been kept anonymous. Anonymity was not implemented in Appendix D because of the difficulty of doing so in the large spreadsheet. For this reason, public distributions of this report will not include Appendix D without SMUD's prior approval.

Retrocommissioning Participants in Year 1999

- Office1 (352,000 ft2) Construction year unknown
- Hospital1 (267,000 ft2) Const. in 1996
- Office5 (150,000 ft2) Const. in 1995
- Lab1 (94,000 ft2) Const. in 1997

Recommissioning Participants in Year 2000

- Office6 (308,400 ft2) Const. in 1965, complete renovation 1999
- Office2 (383,200 ft2) Const. in 1984
- Office3 (400,000 ft2) Const. in 1991
- Office4 (324,000 ft2) Const. in 1990

Results

The weather normalized energy savings analysis shows an average of 7.3% (4.9% median) annual electricity savings across all eight sites. The retrocommissioning reports predicted an average electricity savings of 4.9% per year (4.0% median) for all eight sites. Post-retrocommissioning savings were on average about 27.5% higher than the report predictions. Natural gas data was not obtained for all eight sites. The four sites with data had and average gas savings of 2.9% (3.3% median). Since the cooling season dominates energy use in Sacramento, the lower natural gas savings only reduced the whole building energy savings to an average of 6.1% (5.4% median).

The aggregate post-retrocommissioning electricity savings calculated by the data analysis are as follows:

Table ES - 1: Aggregate annual energy savings for all 8 sites

Year	2000	2001	2002	2003
Aggregate Savings (MWh/yr)	1,170	4,420	3,850	3,300

The following graph shows the aggregate energy savings with the data in a retrocommissioning year progression instead of calendar year. Each curve represents an aggregate group of sites with the same amount of post-retrocommissioning consumption data. All the sites show increasing energy savings during years one and two. This is expected because the recommended measures are implemented over time (often over a period exceeding one year in duration). After the second year, the increasing savings trend appears to flatten during year three, then degrade in the fourth year.

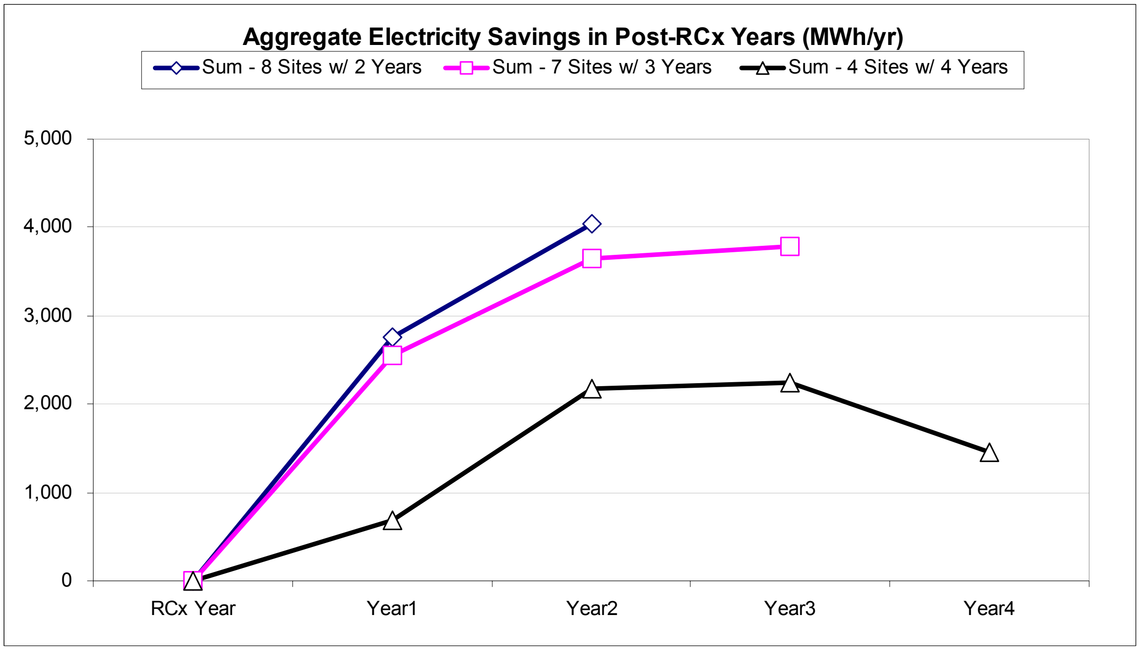

Figure ES - 1: Plot of aggregate post-retrocommissioning electricity savings

The retrocommissioning cost payback was less than three years at each site. The total implementation cost was $61,646 for the 48 recommended measures, an average of approximately $1280 per measure. Floor area normalized retrocommissioning and implementation costs averaged $0.12 per square foot, ranging from $0.06 to $0.41 site by site.

Recommended measures were implemented at a rate of 59% (48 out 81 measures). Implemented measure persistence was strong with an 81% persistence of the recommended system settings. Only four measures were identified as abandoned and not persisting. All four of the not-persisting measures were control recommendations for air distribution components. Five implemented measures did not solve the identified problem, but the sites opted to evolve the settings towards a solution, rather than revert to the pre-retrocommissioning settings.

All of the sites reported that retrocommissioning is a worthy process. Four of the sites listed training as the primary non-energy benefit from retrocommissioning. The most cited downside to retrocommissioning was the time intensive nature of the process.

All of the sites came out of the retrocommissioning process with ideas on how to retain the commissioning benefits over time, the most common solutions being preventative maintenance plans. All the sites would undertake retrocommissioning again, but only two have potential internal funding.

Summary

Some important retrocommissioning process factors that this study identified are:

- The commissioning authority is most effective when they are both an expert and a teacher

- Building engineers prefer to evolve the settings on a recommendation that doesn't work, rather than revert to the previous condition.
- Retrocommissioning appears to raise energy efficiency awareness
- Retrocommissioning funds are constrained within building management budgets

The energy analysis results showed:

- Analyses should not emphasize first-year savings because savings typically take two to three years to fully manifest.
- Energy savings is persisting to four years or more, although some degradation begins in the third year
- The retrocommissioning energy use predictions were reasonably accurate
- Building managers lack tools for tracking energy performance
- Retrocommissioning cost pay back was shorter that the apparent savings persistence
- Retrocommissioning focused mostly on electricity savings and some natural gas trade offs in the savings occurred

Recommended Process Improvements

There are several recommendations that this study can provide to the SMUD Retrocommissioning program:

- Develop measure implementation tracking agreements, possibly with inspections
- Explore methods to conduct a three year post-retrocommissioning energy consumption analysis using the billing history
- Develop simple Performance Tracking Tools for the building operators
- Develop an extension to the program whereby participants are eligible for new incentives in year 4 to evaluate and update the retrocommissioning as necessary

On the whole, the SMUD retrocommissioning program's two broad goals appear to have been met at these eight sites. Aggregate post-retrocommissioning savings were strong, peaking at approximately 4,420 MWh and the program has helped educate site staff about energy efficiency and the role operations and maintenance plays.

I. Introduction

A. Project Goals and Objectives

Commissioning of existing buildings is an increasingly important tool for building owners and operators. Large commercial buildings have many energy consuming systems that will degrade or fail without preventative maintenance and attention. The retrocommissioning process is fast emerging as a cost effective method to fine tune or correct problems, often resulting in energy and cost savings. Although retrocommissioning is becoming popular, the question of how long the benefits will endure over time is not well understood.

The Sacramento Municipal Utility District (SMUD) is a public electric utility serving over 500,000 customers. The SMUD retrocommissioning program is designed to reduce overall building energy consumption through low-cost operational improvements and on-site training of building operators. A secondary goal is to guide the customer toward more far-reaching improvements that may become evident in the course of commissioning. Such improvements may include capital intensive energy efficiency retrofits, more advanced operator interface and software, and replacement of the entire controls system and associated equipment.[i]

Retrocommissioning can be defined as follows.[ii]

> Commissioning of existing buildings or "retrocommissioning," is a systematic process applied to existing buildings for identifying and implementing operational and maintenance improvements and for ensuring their continued performance over time. Retrocommissioning assures system functionality. It is an inclusive and systematic process that intends not only to optimize how equipment and systems operate, but also to optimize how the systems function together. Although retrocommissioning may include recommendations for capital improvements, the primary focus is on using O&M tune-up activities and diagnostic testing to optimize the building systems. Retrocommissioning is not a substitute for major repair work. Repairing major problems is a must before retrocommissioning can be fully completed (Oregon Office of Energy, March, 2001).

Obtaining an estimate for the energy savings persistence is difficult due to the many load and occupancy factors. Equally difficult is characterizing the recommended system settings persistence. Building operators often make modifications to system settings in response to ongoing occupant calls. Over time the changes might adversely affect the previously implemented retrocommissioning measures. More understanding of these two persistence conditions will help retrocommissioning attain even more market penetration.

The objective of this study was to examine the current energy performance of buildings that participated in SMUD's commercial building retrocommissioning program and evaluate the persistence of energy savings and extent of recommended measure implementation. Recommendations are then developed to help improve the effectiveness of the program.

This report is organized in five sections. The remainder of the Introduction describes previous related work and the Methodology section provides an overview of the data analysis. Next, the Results and Discussion sections summarize key findings. The Summary section provides conclusions.

B. Previous Commissioning Persistence Studies

Two previous studies have also examined persistence of savings from commissioning. The first study by Texas A&M was a quantitative examination of the persistence of savings in ten existing buildings. They evaluated whole-building energy use data for several years after commissioning.[iii] Texas A&M refers to existing building commissioning as Continuous Commissioning, but it is quite similar to the retrocommissioning of the SMUD program. The Texas A&M study showed that 3 to 4 years after commissioning, about 80% of the energy savings were still present in the 10 buildings studied. The 20% reduction in savings was dominated by an increase in energy use at 2 of the 10 buildings. So, in general, the persistence of savings was quite good. The study included an examination of the status of each of the measures originally included in the retrocommissioning intervention. Several control measure fixes were defeated.

The second study by PECI,[iv] looked at the persistence of savings in new building commissioning and focused on control system changes. The PECI study used a qualitative approach based on interviews, and site visits were conducted. Individual recommended measures were tracked and evaluated. Fifty-five commissioning fixes were studied, and the large majority of the measures persisted. 14 of the 55 did not persist, or about one fourth.

II. Methodology

This study was conducted with six tasks. The first was a review of existing data for the SMUD retrocommissioning program. Next a review of existing persistence literature and decisions on the project methodology were finalized. The next task was to complete a final project plan and site selection. The next steps were the on-site interviews and the final collection of energy use data. Next the data were evaluated and persistence levels were estimated. Finally, the development of recommendations to improve the retrocommissioning program and improve overall persistence were assembled.

A. Site Selection

SMUD provided LBNL with 12 BAS (Building Automation Systems) retrocommissioning reports as well as SMUD's Evaluation reports for the Year 1999 and 2000 Program participants. The Evaluation reports are SMUD's official record of the measures thought to be implemented.

The selected sites included six office buildings, one hospital and one laboratory. Two of the sites, Office1 and Office3, have computer data centers.

Retrocommissioning Participants in Year 1999

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- Office3 (400,000 ft2) Const. in 1991
- Office4 (324,000 ft2) Const. in 1990

B. Site Visit Procedures

Sites visits and multiple telephone interviews with each site were conducted. Our methodology to minimize errors involved asking many questions about the same measures over an extended period of the study. This process is discussed more in the measure persistence methodology section.

For each site visit, LBNL prepared a Project Summary & Interview Questions document, which was provided to each site contact person prior to the visit. The document included a summary of the project goals, commissioning practice references, the preliminary energy analysis results, a list of questions about their retrocommissioning experience and formatted tables for answering questions about the recommended measures and their implementation status.

C. Energy Analysis

Both the Energy Analysis and the Measure Persistence work incorporated elements from the two prior relevant studies discussed in the Introduction. The energy analysis process included three phases: analysis of the local weather history, the production of weather normalized energy consumption data and the comparison of consumption history against a pre-retrocommissioning baseline year. During the last step, adjustments to correct for the 2001 energy crisis and other confounding occupancy patterns were attempted.

Spreadsheets and EModel[v], a weather normalization and energy savings analysis tool, were used to estimate the energy use after retrocommissioning. A more detailed discussion of each analysis phase is documented in Appendix A.

1. Billing History Data

Monthly electricity billing history was obtained for all eight sites. One site had two years of post-retrocommissioning data, three had three years, three sites had four years and the last one had five years. At four sites, 15-minute interval data from a web-based energy information system were also available. This data provided the study some end use metering. Monthly natural billing history was obtained for four sites.

Gaps in utility billing data were filled using data from on site records, or EModel regression estimates.

2. Data Normalization

All of the energy consumption data were normalized to a common average weather year and a common billing period of 30.5 days. This was done with EModel and spreadsheet calculations. This is similar to the methodology used by Texas A&M[vi], with the exception that this study uses an average weather year for all the sites as opposed to selecting a representative year from the actual weather data for each site.

Weather data for Sacramento, CA was obtained from the Average Daily Temperature Archive website (http://www.engr.udayton.edu/faculty/jkissock/weather)[vii]. A regression model was applied to each year of 1997 to 2003 data to produce a monthly profile of average dry bulb temperatures.

The EModel simulations produced weather-normalized energy usage profiles based on monthly energy use versus average monthly outside air temperature. More details on the EModel procedure are provided in Appendix A and detailed output for each site is provided in Appendix B. Conducting the weather and billing period normalization was a core aspect of this study. Having the normalized data allowed quick baseline year adjustments without redoing the EModel simulations. Moreover, the program-wide averages and comparisons are more robust with the normalized data.

3. Savings Calculation

Spreadsheets were used to calculate energy savings and energy use benchmarks. Two sets of savings estimates were calculated, using the normalized consumption data the other using the retrocommissioning report predictions. Both sets of savings (columns C & D in Table 2, p.11) were calculated against the same normalized baseline. The savings predictions were done measure-by-measure in the retrocommissioning report. Two of the retrocommissioning reports, Lab 1 and Hospital 1, included a 20% savings discount for the all-measures total. The only calculation explanation provided by the two reports is that the "percentage reduction estimate is considered to give a conservative savings total." The other six reports did not discuss the issue of interactive effects. The Table 2 results are based on the average annual savings of only the implemented measures, calculated as the mean difference of each post-retrocommissioning year's electricity consumption against the baseline year.

At Office 2, new chillers were installed in 2002. The savings estimates for Office 2 in this report have been adjusted with chiller plant sub meter data to eliminate the savings associated with the capital intensive retrofit.

The energy cost savings calculation used the average utility rate as documented by the retrocommissioning report. Electric demand charges are not included in the average electricity rate and demand reductions were not tracked by this study.

During the interviews, retrocommissioning and measure implementation costs were gathered. The costs fell into three categories: SMUD's retrocommissioning costs, the Site's retrocommissioning costs and the Site's retrocommissioning measure implementation costs. The cost to SMUD at each site was $25,000. The Site's retrocommissioning costs were defined as any costs the site absorbed to accommodate the commissioning team's field work (e.g., billed time to generate BAS trends, building engineer escorts, etc.). The measure implementation costs include the material and time costs. This category has the widest margin of error, because all of the sites were innovative at finding ways to implement the measures they wanted. In many instances they found "in-between" time for their staff to do the work or found ways to include the work within the scope of service contracts already in place. At two sites, Office1 and Office6, the building engineers provided one implementation cost estimate for all the implemented measures.

A cost effectiveness estimate of the retrocommissioning program was conducted by calculating simple paybacks using the sum of the three cost categories. Paybacks were calculated for the savings predicted by the retrocommissioning report and from the normalized consumption data. The results are presented in Table 7(p.16).

More detailed documentation of analysis calculations are provided in the Appendix A discussion and the Appendix D spreadsheet (CD provided with Hard copies).

D. Measure Persistence Analysis

The measure persistence analysis used site visits and interviews to determine the current status of the recommended measures. A three-phase interview method was used to improve accuracy. The first phase consisted of a questionnaire provided prior to the initial site visit. At the site visit, if access to the BAS was available the measure settings were checked. The second phase involved telephone interviews in which all the measure implementation questions were rephrased and posed again. The third phase was yet another round of telephone interviews, as well as email correspondence, but this time the questions were limited to the discrepancies uncovered between the first two phases.

Parts of the interview history are documented in the spreadsheet (Appendix D) used to finalize the energy analysis. Additional questions about the retrocommissioning process and its effect on building operations, Table 10 (p.19), are documented in the Appendix C interview.

In an effort to track measure persistence trends, each recommended measure was assigned a component letter code and an intervention strategy code. The categories are listed in Table 1. For example, a recommendation to modify the supply air reset schedule of an air handler would be assign the code A-CR1.

Table 1: Measure category key

Measure Categories			Code Letters
Component	Cooling plant		C
	Heating plant		H
	Air distribution		A
	Lighting		L
	Plug Loads		R
	Whole Buidling		W
Strategies	Design, Installation	Change equipment	DI1
		Install controller	DI2
	Control	Reset	CR1
		Sart/Stop	CR2
		Scheduling	CR3
		Modify setpoint	CR4
		Calibration	CR5
	O&M	Manual operation	OM1
		Maintenance	OM2

After the current measure status was determined, we identified each implemented measure as being in one of three persistence states: 1) persisting as implemented, 2) not-persisting as implemented or 3) evolved from the originally implemented settings. The third category for measures that are ‘evolved’ was added to capture measures that were tried, but eventually changed to something fundamentally different than the original settings. The results of the implemented measure survey are presented in Table 8 (p.17).

III.Results

A. Energy Savings

The energy savings analysis shows an average of 7.3% (4.8% median) electricity savings per year across all eight sites. The retrocommissioning reports predicted an average electricity savings of 4.9% per year (4.0% median) for all eight sites. The predicted savings totals are limited to the recommended measures that were implemented.

Table 2: Summary of electric savings

Building	A Predicted Avg Annual Elec.savings (MWh/yr)	B Post-RCx Avg Annual Elec.savings (MWh/yr)	C Predicted Avg Annual Elec.savings (%)	D Post-RCx Avg Annual Elec.savings (%)	E Baseline Electricity (MWh/yr)	B/A Percent of Post-RCx vs Predicted Elec. Savings
Office1	380	190	7.3%	3.6%	5,210	50%
Office2	490	360	7.5%	5.5%	6,604	73%
Lab1	520	620	16.1%	19.3%	3,190	119%
Hospital1	460	430	4.7%	4.4%	9,850	93%
Office3	90	300	1.0%	3.4%	8,584	333%
Office4	120	290	2.2%	5.4%	5,327	242%
Office5	170	220	3.4%	4.3%	4,996	129%
Office6	140	610	2.9%	12.5%	4,827	436%
All Sites	2,360	3,010	4.9%	6.2%	48,588	128%

Column B/A of Table 2 compares the difference between predictions and the calculated electricity savings. Post-retrocommissioning savings were on average about 27.5% higher than the report predictions. Three sites had predictions that were larger that the post-retrocommissioning energy use. The retrocommissioning reports predicted an average annual savings of 2,360 MWh per year and the actual energy use reductions are estimated at approximately 3,010 MWh.

Table 3: Summary of electricity savings by year

Baselines are shaded		1998	1999	2000	2001	2002	2003
Office1 *	% Savings		**0%**		5%	2%	0%
	EUI **		**33.7**		32.7	33.2	34.6
	MWh/yr		**0**		270	130	10
Office2	% Savings			**0%**	15%	11%	15%
	EUI			**17.2**	14.7	15.4	14.7
	MWh/yr			**0**	970	700	990
Lab1	% Savings	**0%**	2%	16%	29%	26%	24%
	EUI	**33.9**	33.4	28.4	24.2	25.0	26.0
	MWh/yr	**0**	50	530	910	840	750
Hospital1	% Savings		**0%**	4%	6%	8%	5%
	EUI		**37.4**	35.9	35.2	34.5	35.6
	MWh/yr		**0**	390	590	770	470
Office3	% Savings		**0%**	4%	5%	3%	-2%
	EUI		**21.7**	21.0	20.6	21.1	22.2
	MWh/yr		**0**	310	440	230	-180
Office4	% Savings				**0%**	4%	7%
	EUI				**16.4**	15.8	15.3
	MWh/yr				**0**	200	380
Office5	% Savings		**0%**	-1%	12%	6%	6%
	EUI		**14.7**	14.8	12.9	13.7	13.7
	MWh/yr		**0**	-60	620	330	330
Office6	% Savings			**0%**	13%	13%	11%
	EUI			**15.7**	13.6	13.5	13.9
	MWh/yr			**0**	620	650	550
All Sites - Total MWh			**0**	**1,170**	**4,420**	**3,850**	**3,300**

* Estimated Baseline from 1998 - 2000 data. ** Energy Use Intensity (kWh/sf^2 yr)

Table 3 shows the calculated post-retrocommissioning energy savings and Energy Use Intensities (EUI) for each year. The annual totals show that these eight sites produced a peak electricity savings of 4,420 MWh in 2001.

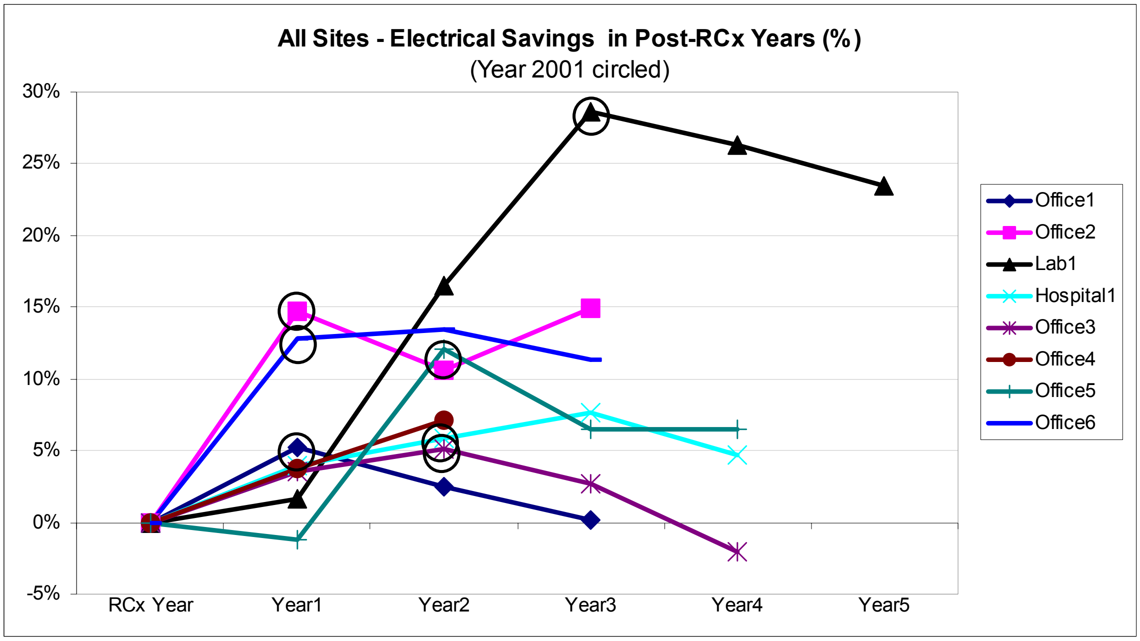

Figure 1: Electrical energy savings in post-rcx years (%)

Figure 1 shows the percent energy saved at each site versus a retrocommissioning year progression. Seven of the sites had 2001 fall into post-retrocommissioning years, as indicated with circles on Figure 1. The curves show that at four sites, 2001 was the peak post-retrocommissioning electricity savings year. This may be a significant trend that shows those sites increased energy conservation activity due to the 2001 California energy crisis.

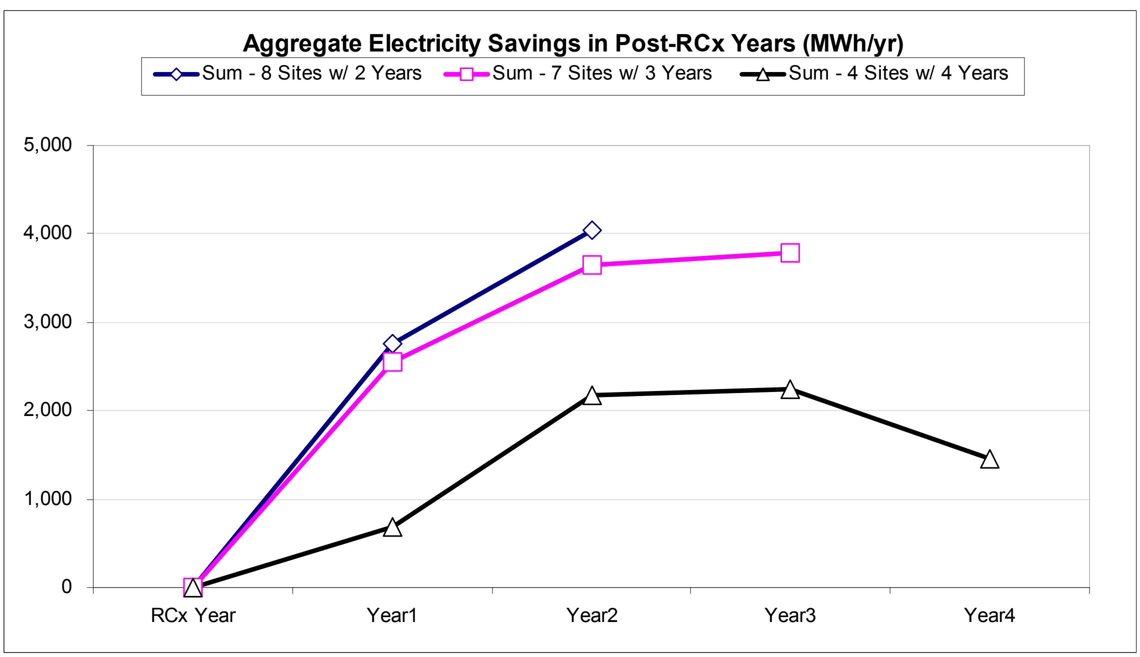

Figure 2: Plot of aggregate post-retrocommissioning electricity savings

Figure 2 shows the energy saved when the data are arranged by years after the retrocommissioning baseline. Each curve represents an aggregate group of sites with the same amount of post-retrocommissioning consumption data. All the sites show increasing energy savings during years one and two. This is expected because the recommended measures are implemented over time. After the second year, the increasing savings trend appears to flatten during year three, then begin to reduce in the fourth year.

Table 4: Electricity savings in post-commissioning years (MWh/yr)

(2001 years are shaded)	RCx Year	Year1	Year2	Year3	Year4	Year5
Office1	0	270	130	10		
Office2	0	970	700	990		
Lab1	0	50.0	530	910	840	750
Hospital1	0	390	590	770	470	
Office3	0	310	440	230	-180	
Office4	0	200	380			
Office5	0	-60	620	330	330	
Office6	0	620	650	550		
Sum - 8 Sites w/ 2 Years	0	2750	4040			
Sum - 7 Sites w/ 3 Years	0	2550	3660	3790		
Sum - 4 Sites w/ 4 Years	0	690	2180	2240	1460	

The values for Figure 2 are listed in Table 4. The Year 2 aggregate has three sites with 2001 data. Approximately 1,860 MWh of the year 1 and 1,650 MWh of the year 2 reductions are from savings occurring in 2001.

Unfortunately, this study did not obtain natural gas consumption for all eight sites. However, the four sites listed in Table 5 provided enough natural gas data, to calculate some whole-building energy results.

Table 5: Four sites – Summary of whole building savings (electricity & n. gas)

Building	A Post-RCx Avg Annual Elec.savings (%)	B Avg Annual N. Gas savings (Therms)	C Post-RCx Avg Annual N. Gas savings (%)	D Baseline Natual Gas (Therms)	E Whole Building Energy (MBtu/yr	F Whole Building EUI (kBtu/ft2 yr)	G Avg Annual Whole Building EUI savings	H Post-RCx Avg Annual Whole Building EUI savings (%)
Office2	5.5%	8,950	15.7%	57,100	28,300	74	5.6	7.6%
Hospital1	4.4%	4,990	1.8%	277,100	60,800	228	7.4	3.2%
Office4	5.4%	-3,370	-10.7%	31,500	3,000	65	2.0	3.1%
Office6	12.5%	2,690	4.8%	55,700	21,900	71	7.6	10.7%
All Sites	7.3%	13,260	2.9%	421,400	114,000			6.1%

A problem with the natural gas analysis was that the retrocommissioning reports rarely provided a prediction for the natural gas consumption. At the four sites with natural gas data, the average electrical savings was 7.3% (7.0% median) but the natural gas consumption was 2.9% (3.3% median). Since the cooling season dominates energy use in Sacramento, the lower natural gas savings only reduced the whole building energy savings to an average of 6.1% (5.4% median) at the four sites (Column H, Table 5).

Table 6: Four sites - Summary of whole building energy (electricity & nat. gas) savings by year

Baselines are shaded		1999	2000	2001	2002	2003
Office2	% Savings		**0%**	16.6%	16.3%	21.2%
	EUI		**73.7**	61.5	61.7	58.1
	MBtu/yr		**0**	4,683	4,598	5,998
Hospital1	% Savings	**0%**	3.4%	7.4%	1.5%	No gas
	EUI	**227.6**	220.0	210.8	224.2	Data
	MBtu/yr	**0**	2,044	4,492	-4,470	
Office4	% Savings			**0%**	3.0%	No gas
	EUI			**65.3**	63.4	Data
	MBtu/yr			**0**	-337	
Office6	% Savings		**0%**	15.5%	7.7%	8.8%
	EUI		**70.9**	59.9	65.4	64.7
	MBtu/yr		**0**	3,387	1,691	1,930
Four Sites - Total MBtu/yr		**0**	**2,044**	**12,563**	**1,482.5**	**7,928**

* EUI values are kBtu/sf² yr

Table 6 and Figure 3 show the calculated post-retrocommissioning whole building energy savings and EUI for each year.

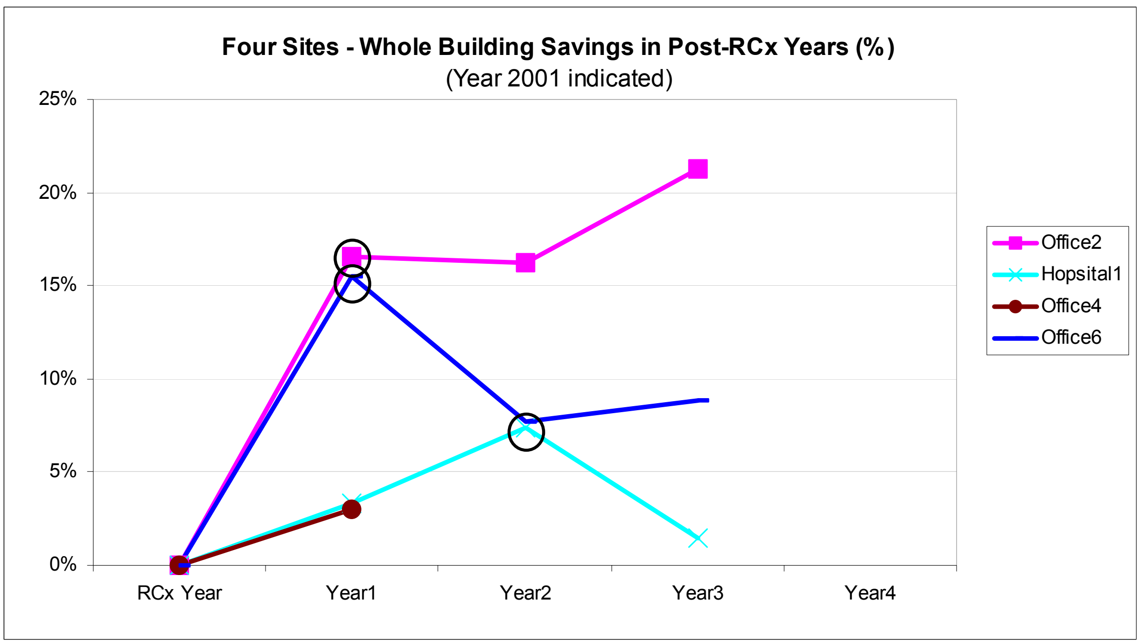

Figure 3: Four sites - Whole building energy savings in post-rcx years (%)

Overall, the inclusion of natural gas data reduced whole building energy savings slightly, but did not significantly change the savings profile.

1. Cost Effectiveness Analysis

Table 7 (p.16) summarizes the retrocommissioning costs and paybacks for each site. All of the implementation costs were moderate, with a total implementation cost of $61,646 for the 48 recommended measures. This total cost excludes a capital-intensive recommendation, at Office 2, to install new chillers, because the chiller change-out is a capital equipment energy savings measure rather than a commissioning measure. Office 3 kept costs down by doing the work under an existing service contract. All the paybacks are attractive. The floor-area-normalized costs ranged from $0.06 to $0.41 per square foot. Compared to traditional capital intensive energy audits, these costs range from opportunity assessment to investment-grade audit prices.

Table 7: Table of retrocommissioning costs & simple paybacks

Building	RCx Study costs (Agent cost $25k, balance incured by site)	Estimated Measure Implmnt. costs	Predicted Avg Annual savings ($)	Post-RCx Avg Annual savings ($)	Predicted Simple Payback	Post-RCx Simple Payback	RCx Study Costs ($/sf)	RCx Study & Implement. Costs ($/sf)
Office1	$28,000	$1,710	$24,500	$13,000	1.2	2.3	$0.19	$0.20
Office2	$26,500	$20,500	$21,900	$27,900	2.1	1.7	$0.07	$0.12
Lab1	$26,000	$12,370	$64,800	$40,100	0.6	1.0	$0.28	$0.41
Hospital1	$28,300	$11,180	$35,200	$30,900	1.1	1.3	$0.11	$0.15
Office3	$25,400	$150	$6,400	$22,400	4.0	1.1	$0.06	$0.06
Office4	$26,817	$8,380	$8,400	$22,600	4.3	1.6	$0.08	$0.11
Office5	$26,817	$4,350	$9,100	$15,800	3.4	2.0	$0.08	$0.09
Office6	$26,700	$3,000	$11,200	$48,600	2.7	0.6	$0.09	$0.10
All Sites	$214,533	$61,650	$181,600	$221,200	1.5	1.2	$0.09	$0.12

B. Measure Persistence

Measure persistence among the implemented recommendations appears to be good, with 81% identified as still persisting with the system settings that were recommended. The current persistence state of the implemented measures are listed in Table 8 (p.17). Only four measures were identified as being abandoned completely and as such are not persisting. All four of the non-persisting measures were control recommendations for air distribution components.

Table 8: Summary of persistence status for implemented measures

	Office1	Office2	Lab1	Hopsital1	Office3	Office4	Office5	Office6
Measure Category Codes	C-CR2(y)	A-CR4(y)	W-OM1(y)	A-CR3(e)	A-CR5(y)	A-CR5(y)	A-DI1(y)	A-CR2(y)
	C-CR2(y)	L-DI2(y)	A-DI2(y)	A-CR4(y)	A-CR1(n)	H-CR2(y)	A-OM2(y)	H-CR2(y)
	H-CR2(y)	C-DI1(y)	A-DI2(y)	A-CR3(y)	C-CR2(n)	A-CR5(n)	A-CR1(n)	C-CR2(e)
	A-CR4(y)		A-CR4(y)	A-CR3(y)		H-CR3(y)	A-OM2(y)	C-DI1(y)
	A-CR5(y)			C-CR4(y)		C-DI2(y)	A-OM2(e)	C-CR4(y)
	L-CR3(y)			C-CR4(y)			A-DI2(y)	C-CR1(e)
				C-DI1(y)			H-CR2(y)	A-CR5(y)
				L-OM1(y)				C-CR1(e)
				L-OM1(y)				
				L-CR3(y)				
				L-DI2(y)				
				L-DI2(y)				
Category & Status ID (y = Persists, n = Not-Persisting, e = Evolved)								

Five implemented measures did not solve the identified problems to the building engineers satisfaction and they chose to evolve the measures to find a better solution. Three are control settings on a cooling plant, and the other two are air distribution measures.

Table 9: Count of implemented & not implemented measure categories

Measure Categories			Code Letters	Implemented Tally	Not Implemented Tally	% Implemented
Component	Cooling plant		C	13	8	62%
	Heating plant		H	5	4	56%
	Air distribution		A	22	13	63%
	Lighting		L	7	5	58%
	Plug Loads		R	0	1	0%
	Whole Buidling		W	1	0	100%
Strategies	Design, Installation	Change equipment	DI1	4	6	40%
		Install controller	DI2	7	4	64%
	Control	Reset	CR1	4	6	40%
		Sart/Stop	CR2	9	1	90%
		Scheduling	CR3	6	2	75%
		Modify setpoint	CR4	7	3	70%
		Calibration	CR5	5	5	50%
	O&M	Manual operation	OM1	3	2	60%
		Maintenance	OM2	3	3	50%

The eight retrocommissioning reports recommended a total of 81 corrective measures and 48 were implemented. Air distribution related measures are the most popular in the list with 43% of the component count. Cooling plant related measures are next with 26% of the count. The distribution of recommended strategies is even, with start/stop controls having a slight edge. Only one of the ten recommended start/stop measure was not implemented. Start/stop measures were defined as equipment control settings that are based on environmental parameters such as outside dry bulb temperature. Scheduling measures were defined as equipment control settings that are occupancy based.

IV. Discussion

In general, based on the energy reduction trends at each site, we found that all of the sites had very good cost effectiveness from the retrocommissioning service. The persistence results in Figure 2 and the payback periods in Table 7 (p.16), show that the cost paybacks are within the time frame of persisting energy savings. The longest payback was two years and Figure 2 shows that on average the savings don't begin to show reduction until the fourth year.

An important factor in this study is that there are confounding effects due to the 2001 energy crisis. Four sites report that they responded to the crisis with operation changes such as de-lamping, turning off unnecessary hallway lighting and softening thermostat settings. The post-retrocommissioning data shows five sites have increased energy savings during 2001. On the same token, passing of the crisis (and reduced attention to energy management) may have contributed in part to the apparent reduction in persistence of the savings.

The energy savings benefits are clearly persisting for three years or more at six sites. Only two sites show sharply reduced energy savings in 2003.

At Office1, the recommended measures are implemented at a high rate and the persistence of recommended settings are also reported as high. This conflicts with the apparent lack of energy savings persistence. This could be due to missing energy consumption data for all of 1999 and most of 2000. Also a factor are difficulties in isolating the energy use of the facility's computer data center, which doubled in size to approximately 9000 ft^2 during 2000. Another factor was difficulty in obtaining information from the site personnel. They were consistent in their survey answers in all three phases, but the systems are actually maintained by a subcontractor that we did not interview.

The Office 3 site reported poor interactions with the retrocommissioning authority during field work. The chief engineer identifies the non-existent training benefit as a major disappointment. He also reports significant errors in the retrocommissioning report. As a result, only one recommended measure was implemented (Table 8, p.17). The measure recommended that all sensors be calibrated, which resulted in immediate energy savings. Their operation now recalibrates all sensors every six months. This facility also has a large computer data center, operated by a tenant. There was no discussion of the computer data center in the retrocommissioning report.

Recommended measures were implemented at a rate of 59% (48 out 81 measures). In 19 cases the recommendations were rejected due to a conflicting opinion about the retrocommissioning analysis or the cost was prohibitive. In seven cases, the sites said they would revisit the measures in the future. Another seven recommended measures have plans for implementation. In at least two cases, erroneous assumptions were made and the recommendations should not have been offered. In both cases, better communication with the building operators would have preempted the recommendations. In three cases, no reasons were provided for rejecting the recommendations.

One measure, wet bulb reset control for the condenser water temperature, was recommended in exactly the same fashion at three sites. All three sites rejected the recommendation. The apparent rejection of the "cookie cutter" measure by all the sites reinforces the importance to keep the retrocommissioning recommendations specific to the facility's systems.

From the outset of data collection, direct access to the candidate buildings for inspections was hampered due to the busy schedules that the building managers, engineers and operators have.

Seven sites reported that the retrocommissioning process inspired a more innovative analysis of their systems and in many cases prompted them to find other retrocommissioning like improvements. This factor is an important benefit that should not be overlooked and is directly related to a retrocommissioning process that involves the building operations staff as much as possible. In a large percentage of instances, a properly executed retrocommissioning process will inspired a more creative approach to building operations and maintenance that might not have previously existed.

Table 10 lists the sites' answers to eight key questions about their retrocommissioning experience. The blank cells mean the site did not answer the question. The complete list of questions and answers for each site are provided in Appendix C.

Table 10: Answers to survey questions about Retrocommissioning process

Building	Primary non-energy impact of RCx	Most negative impact of RCx	Level of Training obtained	Plans to improve persistence	Will you RCx again	Do you have funds for RCx	How did you pay for RCx costs	How did you find out about SMUD RCx
Office1	Review of Sys. Specs.	None		Maintenance Manager program	Yes	No	O&M Budget	SMUD RCx dept.
Office2	Equip. life improvement	Time Req.	High	Utility Manage. plan	Yes	No	O&M Budget	SMUD Rep.
Lab1	Training	Time Req.	High	Improve WO process	Yes	Possible	O&M Budget	SMUD RCx dept.
Hospital1	Training	Time Req.	High	Create an Energy Group	Yes	No	O&M Budget	SMUD Rep.
Office3	Training	None	None	Chief Eng. - approves all changes	Yes	No	O&M Budget	SMUD Rep.
Office4			Low	PM plan	Yes	No	O&M Budget	SMUD Rep.
Office5	Review of Sys. Specs.	Tenant interactions		PM plan	Yes	No	O&M Budget	SMUD Rep.
Office6	Training	Time Req.	High	BAS maint. Contract	Yes	Yes	O&M Budget	SMUD Rep.

Four sites listed training as the most important non-energy benefit. Many of the building engineers characterized the commissioning authority as a "teacher." Table 3 (p.12) results show that the four sites that said that they received a high level of training value also had good energy savings persistence. Conversely, Office3 reported virtually no training value and this site shows poor energy savings persistence.

The most cited downside to retrocommissioning was the time-intensive nature of the process. Also notable are two building engineers that could not find any negative aspects of retrocommissioning. Only one site identified inconvenience to the tenants as a problem.

All of the sites came out of the retrocommissioning process with ideas on how to retain the commissioning benefits over time. The most common solutions are preventative maintenance plans (not all the sites called it a PM plan). Office6 hired a BAS expert with the task of providing small commissioning style reviews each month. The Hospital 1 site is creating an Energy Issues Group among their building operations staff.

All the sites would undertake retrocommissioning again, but only two have the chance for internal funding to do so. The other sites report that they are dependent on external funding for the cost of retaining a commissioning authority.

None of the sites sought out SMUD for the retrocommissioning program. Either their SMUD account representative or an employee of the SMUD commercial building services department recruited them.

An additional comment provided by Office 5 was that the retrocommissioning exposed some errors and inadequacies of the new construction commissioning that was conducted in 1995. For example, they found sensors inside walls and, fundamental duct static pressure and fan speed problems.

V. Summary

The persistence of retrocommissioning benefits, both non-energy and energy related, are significantly affected by how the process is executed. Especially important is the conduct of the commissioning team during field work. Some important process factors that this study identified are:

- **Commissioning authority attitude** – A superior attitude can hinder information flow in the process. Commissioning authorities are most effective when they are both an expert and a teacher.
- **Identification of a retrocommissioning measure is just the start** – Retrocommissioning measures do not always work. Finding options that allow building engineers the opportunity to evolve towards a final solution is desirable.
- **Retrocommissioning can raise energy efficiency awareness** – Independent of whether the retrocommissioning effort was successful, all eight sites exhibited an increased awareness of energy efficiency and building diagnostics issues.
- **Retrocommissioning funds are constrained** – SMUDs program does not provide funds for retrocommissioning project implementation. However, all of the survey sites internally funded projects meeting their cost-effectiveness constraints.

The energy analysis results showed:

- **Measure implementation occurs slowly** – Analyses should not emphasize first-year savings because savings typically take two or more years to fully manifest.

- **Energy savings degraded in the fourth post-retrocommissioning year** – The energy data appears to show that persistence turns a corner after three years and begins to show signs of reduction. However, this finding is confounded by extraordinary energy savings efforts made during the 2001 energy crisis.
- **The retrocommissioning energy use predictions are reasonably accurate** – The retrocommissioning authorities under predicted energy savings at the eight sites by 27.5%.
- **Building managers lack tools for tracking energy performance** - Only 3 of the building operations staff had access to energy consumption analysis tools. The remaining facilities did not have any resources other than monthly utility bills.
- **The cost payback was shorter than the apparent savings persistence** – The calculated simple paybacks were shorter than the four years of energy savings. The results indicate that the complete costs of retrocommissioning could haven been absorbed into the property management's internal budgets.
- **The retrocommissioning focused heavily on electricity savings** – This is a natural expectation since SMUD is not a natural gas supplier and cooling dominates costs in Sacramento. However, the natural gas data show trade-offs between electricity and natural gas consumption at some sites. From the customer's perspective, cost savings might have been improved if the process more carefully considered interactive effects between cooling and heating.

A. Recommended Process Improvements

There are several recommendations that this study can provide to the SMUD Retrocommissioning program:

- **Develop measure implementation tracking agreements** – SMUD's records on the measure implementation status were inaccurate for all eight sites. Project contracts with specific language that provides inspection level access to the system could improve the accuracy.
- **Explore methods that can provide a three year post-retrocommissioning energy consumption analysis** – An EModel style analysis of the program participant's billing history, approximately three to four years after retrocommissioning, could provide better feedback on the savings persistence. This level of analysis can be designed into a relatively low cost production process requiring modest technical skills.
- **Develop Performance Tracking Tools** – All the building engineers expressed a need for performance tracking tools. If adequate tools were available, they could monitor key metrics that indicate when persistence is degrading and quickly respond with corrections.
- **4th Year Retrocommissioning Measures Review** – Consider adding a component to the Program to foster re-assessment of the retrocommissioning measures in the fourth post-retrocommissioning year.

On the whole, the SMUD retrocommissioning program's two broad goals appear to have been met at these eight sites. The goal to reduce overall building energy consumption appears to be fulfilled, with the aggregate post-retrocommissioning savings peaking at approximately 4,420 MWh in 2001. A significant a portion of the savings came from low-cost operational improvements and on-site training of building operators, but an unquantifiable percentage also came from emergency measures associated with the 2001 energy crisis.

SMUD's second goal of guiding their customers toward more far-reaching improvements, is also apparent among these sites. The retrocommissioning process has been a factor in customers' increased awareness of energy efficiency and the positive impact that operations and maintenance can have on energy use.

B. FUTURE DIRECTIONS

Additional research is needed to examine whether the trends identified concerning the persistence of savings from retrocommissioning that occurred in this project are similar at other sites. The findings from this project are similar to the findings from previous research suggesting that most of the savings persist beyond three years. To better estimate of the impact of the 2001 Energy Crisis, these results should be compared against consumption data for similar buildings that did not participate in SMUD's retrocommissioning program. Longer multi-year studies are also needed to examine five year savings rates and beyond. Additional research is also needed to develop tools and methods to allow building engineers and operators to obtain feedback on savings associated with retrocommissioning. Diagnostics tools and continuous performance monitoring systems are needed to assist in such tracking.

ACKNOWLEDGEMENTS

This project was funded by the Sacramento Municipal Utility District (SMUD) and the California Institute for Energy and the Environment (CIEE), previously the California Institute for Energy Efficiency. We thank the generous interest and support of this study by Jim Parks, Dave Bisbee, Richard Green and Mazen Kellow at SMUD. Thanks are also extended to Karl Brown at CIEE. We also wish to acknowledge the time provided by each site contact and their patient answers to the long list of questions. Without their support, this work is not possible.

Thanks are also extended to Evan Mills (LBNL) for his technical review of the final report.

This work was also supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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